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11. CLOUDINESS ASSOCIATED WITH LARGE-SCALE SYNOPTIC SYSTEMS IN TEMPERATE LATITUDES

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The most striking patterns which have been found in the TIROS satellite pictures are the large-scale vortex cloud systems, associated cyclones, their frontal systems, and other details about the patterns. Anticyclonic cloud patterns are also sometimes identifiable. A few cases that have been studied in areas in the Pacific Ocean, the United States, and the Atlantic Ocean will be presented; some Southern Hemisphere cases will also be presented.

Figure 11–1 shows a series of pictures of Northern Hemisphere cyclones taken by TIROS I. Briefly, these pictures show cyclones in various stages of development. Picture 1 is a rather young cyclone, picture 2, is a cyclone a little further in its development, picture 3 is a rather old cyclone and further advanced in its occluded stage, and finally the most developed storm is seen in picture 4, in which only a part of the storm can be seen.

The appearance of these cyclones varies. Sometimes a white cloud mass is seen; it is white because the solar energy is being reflected to the satellite. In the pictures very dark re-

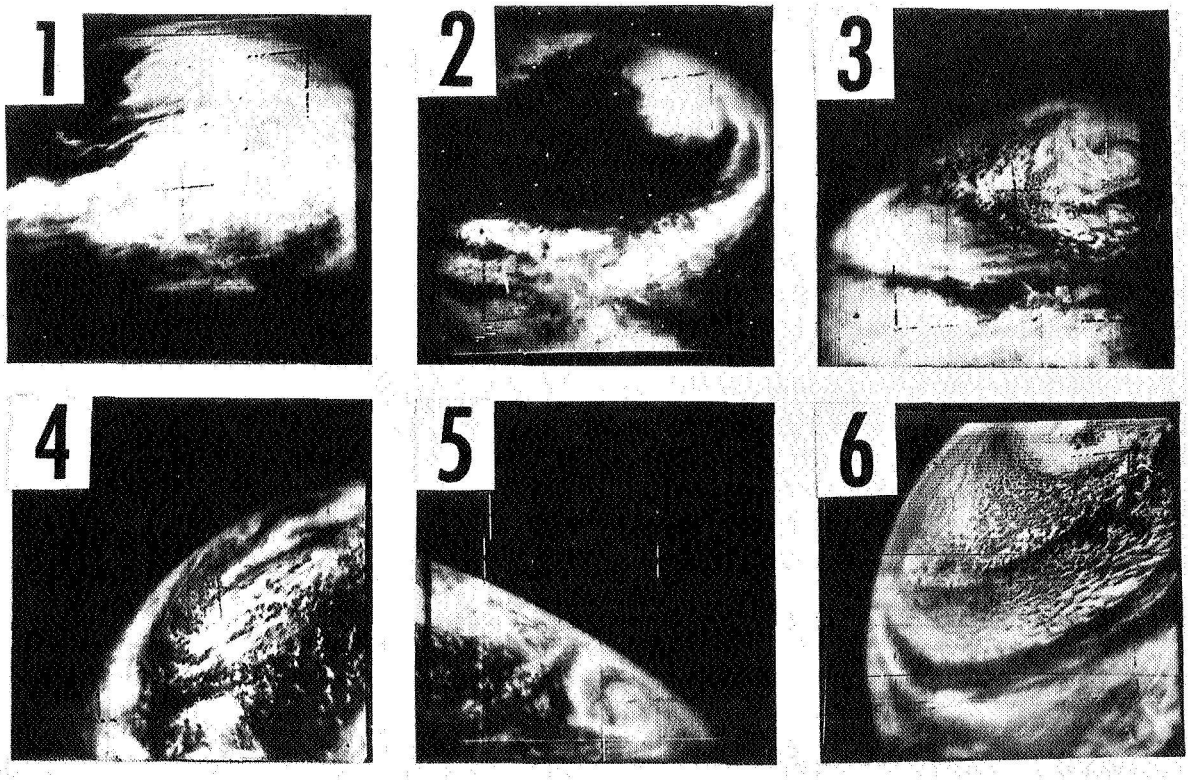

FIGURE 11–1. Northern Hemisphere cyclones.

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gions are also seen, which represent, for the most part, cloudless regions and can be assumed to be cold air that is invading the area occupied by white clouds.

Sometimes, as in picture 6 of figure 11–1, a strip of cloudless air is actually embedded in the main cloud system. In addition, the streakiness of the clouds in the spiral array can be seen. The extent of streakiness in the atmosphere is perhaps a little surprising in comparison with what was expected before TIROS. The atmosphere displays a great deal of streakiness. Darker strips are embedded in the more or less overcast bright regions, as in pictures 2 and 3, and are also seen in cloud streets, some of which will be shown subsequently. The outlines of the cyclonic patterns are thus seen in at least these two ways: cold air coming into the cloudy area and streakiness in the upper cloud system.

Consider, now, how such information may be used. There are ways of locating geographically the various cloud elements that are seen in the pictures. For example, in the case of the cyclones, the theoretical center of the spiral pattern can be located. It is also fairly clear that in some regions of the world the mere location of cloud systems will be of considerable help; such areas are, for example, the regions that bound South America both to the east and to the west, the region that surrounds Africa, and the region to the south of Australia. These are regions from which there are very few reports; there are no islands, very few ships, and very few airplanes. Thus, they are areas of almost complete meteorological silence. The mere knowledge of the location of a system in those regions can be of great use for forecasting.

It should be recognized that the satellite is not a forecaster. It can only observe. Every forecast system has as its beginning some information about the initial state of the atmosphere. The satellite serves as a very important observing tool which can provide information about atmospheric conditions at the beginning of a forecast period. In silent areas, knowledge of the existence and location of a storm, information which except for TIROS might not be known, is very important. This same argument would also hold in the tropical regions where often very little information can be obtained regarding the existence or the location of severe storms, such as hurricanes or typhoons.

In other areas of the world, for example, in the Atlantic Ocean area, in the Pacific Ocean to a lesser extent, or in the North American, European areas, the existence of the larger storms is generally known, although sometimes, by using satellite pictures, it is possible to position the storm more accurately. If a big storm exists in those areas, conventional reports will establish its existence. Some improvement can be made in locating new formations—waves on a front, for example—which might be poorly documented even over ocean shipping lanes. Also, there are cases in which, even in well-covered areas, smaller systems may escape detection and the satellite can help.

Since clouds are produced by physical processes, much information on the present state of the atmosphere, such as the distribution of moisture, the presence of vertical motion, a general indication of wind pattern, and other factors, should be obtainable from the cloud pictures.

On the whole, it is believed that, on the large scale, clouds are produced essentially by upward motions in the presence of the proper humidity field. Thus, the clouds indicate the vertical motions and the humidity field which gave rise to the particular pattern. In the more recently tried forecasting methods, namely numerical weather prediction, equations of motion are modified to fit a particular model and an attempt is made to forecast the future state of the atmosphere. In order to begin the forecast, the conditions of the atmosphere at the beginning of the forecast period must be known. Of primary use in the initial horizontal flow field, that is, the horizontal motions that exist at the beginning of the forecast period. Even in the somewhat elementary models, the vertical motion field, the field of the upward and downward motions of the atmosphere, is computed on the basis of a knowledge, or on an estimate, of the horizontal motions that exist at the beginning of the forecast period.

It is known that in many regions, even in the better observed ocean areas, such as the Atlantic or the Pacific Ocean, the upper air information which must go into such vertical-motion estimates is inadequate. There are an insufficient number of upper air stations. In the Pacific Ocean there are very few. Although there are more in the Atlantic, the number of reports

available is still too small to give a reliable picture of the vertical motion. Nevertheless, computations of the vertical motion are made in these ocean areas on the basis of the information that is available at the beginning of the forecast period. A check on the vertical motion is available if the theory that clouds are produced by upward vertical motions is accepted. Then, the computed vertical motion can be compared with the cloud pictures. If the computed motions do not agree with the cloud pictures, corrections must be made either in the model or in the estimate of the initial flow field.

Perhaps present knowledge does not allow changing the models, but, by accepting the numerical models which are in use, it may be possible to change the initial conditions in such a way as to make the vertical motion field or humidity field agree with the cloud pictures. These cloud observations are now basic; it is hoped that all regions of the world will be observed at least once a day by late 1962 or early 1963.

There are at least two approaches being made to explain the physical nature of clouds. One of these two approaches is a study being conducted by Capt. E. C. Kindle of the U.S. Air Force to develop a numerical method of forecasting the location and extent of cloudiness. The cloud pictures are fitted to the appropriate time step of the computed forecast fields of horizontal flow and vertical motion. This procedure gives a humidity field. By using this field, forecasts are made ahead for a short period, say 4 hours. Then, if cloud pictures are available, these are compared to the forecast humidity field. If the actual cloud pictures do not agree with the forecast of what the clouds should be, on the basis of the computation made using the humidity data together with the motion field, only the initial humidity field is changed to get agreement at the cloud observation time. Once agreement at the cloud observation time is achieved, the computations are continued for several hours more, and then an attempt is made to forecast the cloud field in the future. Thus, the method is a way of obtaining consistency between the motions of the humidity field and the cloud pictures.

In the Meteorological Satellite Laboratory, this problem is being attacked in another way. The humidity field is not changed, but it is assumed that the clouds are an indication of the vertical motion field. The vertical motion field can be computed in several different ways. The results from the numerical prediction system that is used in the Weather Bureau are accepted. An attempt is made to see whether the vertical motion field that is computed from the equations of horizontal motion and the horizontal flow field at the beginning of the forecast period agrees with the cloud observations from the satellite. If it does not agree, ways are being studied to change the initial horizontal flow field—particularly in ocean areas—in such a way that the vertical motion field would agree with the cloud pictures.

The solution is not yet known because this investigation is just beginning. However, it seems that there is a lot more information to be obtained from the large-scale cloud pictures than just the positions of synoptic patterns. With proper research and investigation into the basic nature of the physics that produce the cloud systems, there is hope of having an important input into numerical weather prediction methods.

In the earliest phases of cyclonic systems it is expected that cyclones will often form as waves on preexisting fronts. However, as far as is known, there are no good pictures from the TIROS series of a wave on an extensive frontal system. Figure 11–2, which is a composite of pictures from an Atlas rocket that was fired in 1959, shows what a wave may look like. Puerto Rico, Haiti, Cuba, the eastern coast of the United States, and a part of the western Atlantic Ocean are shown in the figure. The wave on the frontal system never did develop very much. The frontal system has definitely been distorted to the north in the manner which would have been expected from the Norwegian frontal theories on wave development.

There is another feature which is interesting and which is occasionally seen in TIROS pictures. This is the cloud pattern which sometimes outlines anticyclonic areas. In the region of an anticyclone, massive stratiform clouds or continuous layer clouds are not expected; however, small cumulus clouds are often arrayed in lines. These lines often lie close to the wind direction, although how close is sometimes a question. Sometimes they do outline the larger scale anticyclonic flow.

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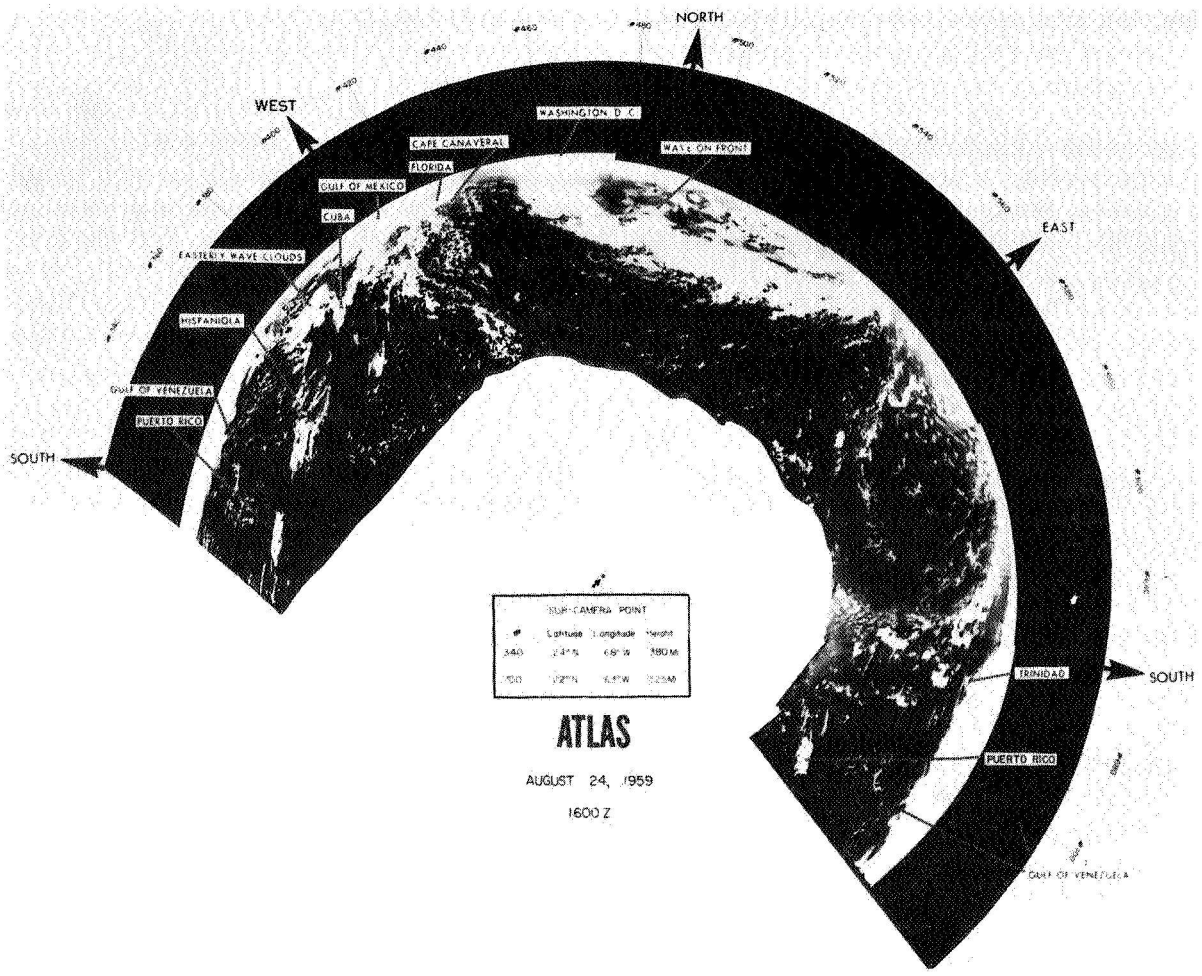

FIGURE 11–2. Mosaic assembled from nineteen frames of Atlas moving pictures. Height range, 380 to 525 nautical miles.

In figure 11–3 a weather map of a cyclone along the eastern coast of the United States, the region around Boston and Cape Cod, is shown. The important point is that, according to the analysis, there is an open-wave cyclone which has not yet occluded; there is also a cloud system showing the circulation. It might be noted that along the coast on the day these pictures were taken there were no clouds reported from the ground or from the satellite; thus, the coastline should be visible. However, the visibility of coastlines is a study in itself. Some coastlines are very difficult to see, whereas other coastlines are very marked. In this case the cloud-free region can be seen, but the coastline is not discernible because the contrast between the land and water is too small.

In figure 11–3, the weak frontal cloud system corresponding to the cold front can be seen. It looks as if it is tapering out at the southern end. The cold air is intruding but has not gone very far into the cloudy air mass. In a good print perhaps some traces of a circulation in the cloud could be seen, but it would be difficult. Mainly, a rather large nondescript cloud mass is seen as well as the dark area representing the cold air which has only begun to enter the main cloud region. This pattern, then, might be characteristic of a young cyclone which is more or less at the beginning of its occlusion process but which has not quite started occluding.

Figure 11–4 does not have anything to do with cyclones. This figure is from TIROS II. The pictures were not so clear as those from TIROS I, but a good deal of information can be obtained from them. This photograph shows the east coast of the United States, including

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Boston, Cape Cod, Long Island, and Chesapeake Bay, with Washington to the west of the bay. The land is very white and the coastline is sharp. An area along the coast is rather dark and then a white area appears again. The

FIGURE 11–3(a). Three overlapping TIROS pictures showing extratropical cyclone centered about 120 miles east of Cape Cod, April 1, 1960.

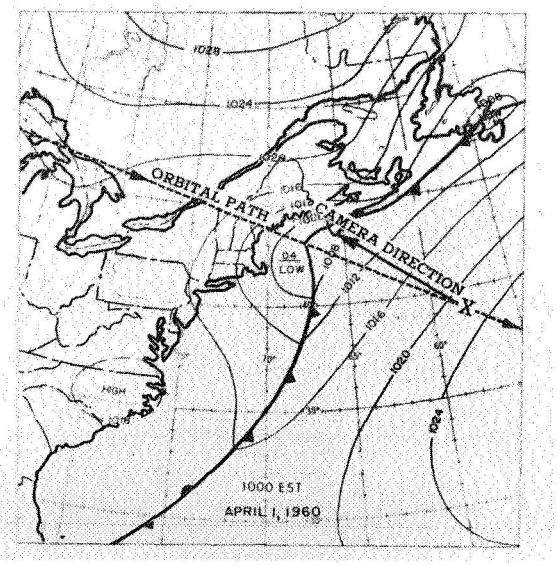

FIGURE 11–3(b). Sea-level weather map, 1000 EST, April 1, 1960. Point X denotes approximate location of satellite and the arrow indicates camera direction when pictures were taken.

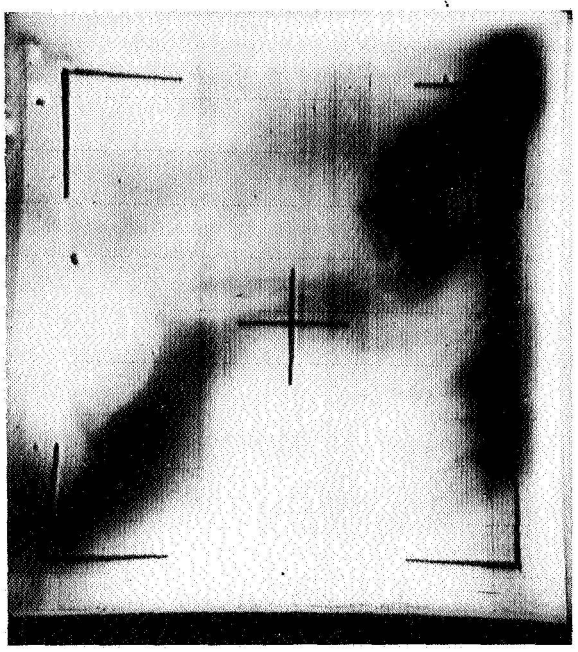

FIGURE 11–4. Photograph taken by TIROS II of snow-covered east coast of United States.

reason that the coast is so well defined is that this picture was taken 2 days after a snowstorm along the east coast of the United States; the land was thus very bright because of the snow. There were practically no clouds over the land area. However, as the air moved out over the warm water, a large-scale cloud mass parallel to a very large section of the coast and at an appreciable distance downwind was produced.

Figure 11–5 shows a cyclone over the middle portion of the United States (studied in detail in ref. 1). This chart was made both from the conventional information and from the satellite picture. The main point to note is the rather large cloud system extending far to the north; this system may be somewhat deceptive in the pictures of figure 11–6. The cloud extends from south of the cyclone center to the north. Also note the shaded areas on this map, which represent radar reports indicating precipitation, and sferics reports indicating thunderstorm activity. These occur at various locations along the front. Figure 11–6 shows the TIROS cloud pictures associated with figure 11–5. Near the horizon the distances are very much foreshortened. A very short distance near the horizon in these pictures represents a very large dis-

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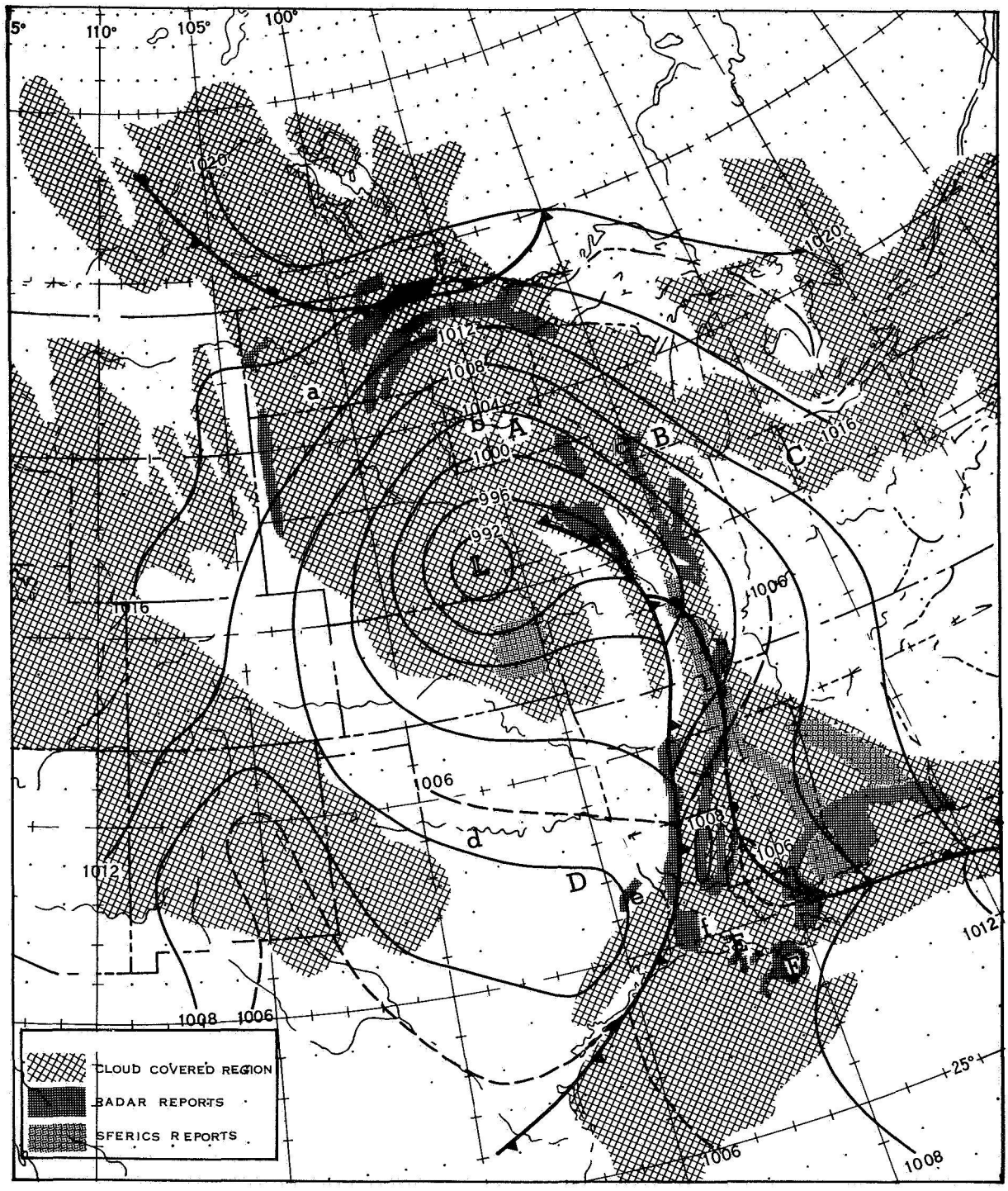

FIGURE 11–5. Sea-level chart, 2100 GMT, April 1, 1960, with cloud cover area and radar and sferics reports. Capital letters refer to photographs taken by the satellite from the positions shown by the matching lowercase letters.

tance on the earth, so that the correct shape of the cloud system cannot be seen. These pictures must be rectified in order to obtain cloud shapes similar to those of figure 11–5. Shown here is the major cloud system associated with the cyclone center and the cold front which extends from the center toward the southern part of the United States. Of note, in connection

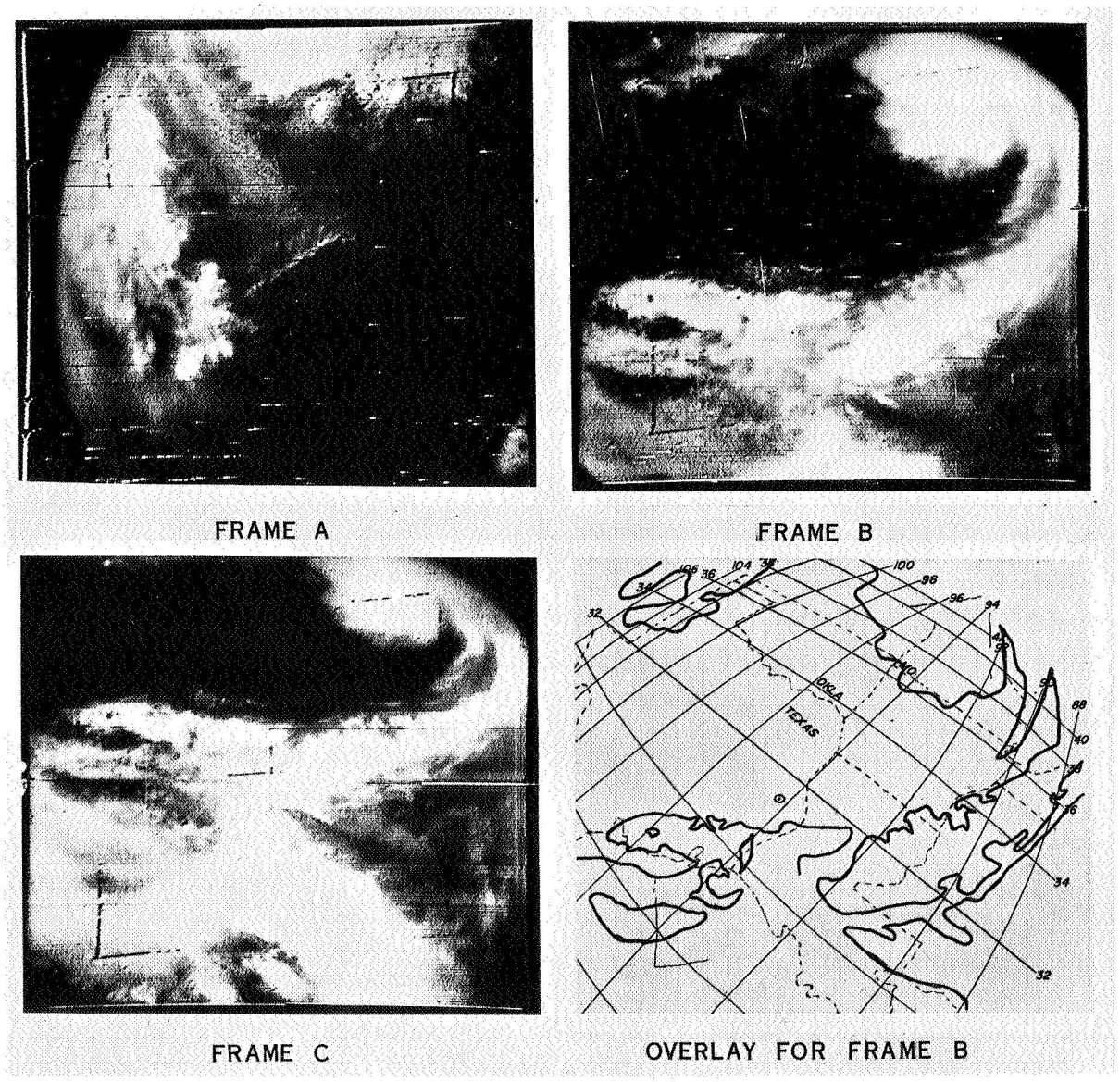

FIGURE 11–6. TIROS wide-angle cloud photographs taken over points A, B, and C of figure 11–5. Grid overlay for frame B.

with the thunderstorms and precipitation along the front, are the gradations in brightness (corresponding to the shaded areas in fig. 11–5) which can be seen in the general area of cloud cover. Another point of consideration is that, if two separate pictures taken at two different places and two different times are examined and the difference in brightness is compared, there is little that can be inferred regarding the vertical developments of the cloud because the brightness of a cloud depends on so many factors.

However, it appears that to a certain extent in a region of general cloudiness, that is, where the area is rather bright everywhere but not uniformly bright, the brighter areas may represent clouds of actual vertical development; that is, clouds of the cumulus congestus and cumulonimbus types tend to be brighter. With reference to the larger scale patterns, the cold air can be seen coming in from the west and northwest, invading the cloud area, frame B, and cutting further into it in frame C. In this case the system has progressed a little further toward the occlusion process; thus, this storm would represent a somewhat older stage of development than the one seen in figure 11–3. There-

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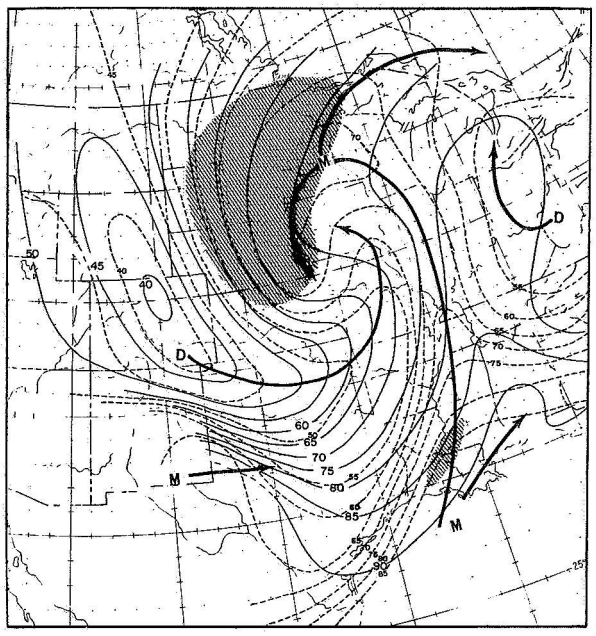

FIGURE 11–7. Isentropic chart for 300° K. Solid lines indicate pressure; dashed lines indicate condensation pressure; 0000 GMT, April 2, 1960; shading indicates approximate area of saturation; pressure given in 10's of millibars.

fore, it would be expected that cold air would continue to flow in behind the frontal system, and perhaps warm moist air would flow into the region along the frontal system.

Figure 11–7 shows an isentropic chart, which is a good way to represent atmospheric conditions. The isentropic chart is a representation which is used to show the airflow in three dimensions. In other words, the air is flowing up along a particular surface or down along a particular surface in the atmosphere. This chart shows the position where the cold front was, just before coming into the cyclonic center. The isentropic surface has its highest point at 400 millibars; in the south the surface is low at 900 millibars. Thus, the moist air flowing from south to north along the line *M* is being lifted upward along the isentropic surface. This chart would indicate an agreement with the previous ideas that the cloud which represented the cold front (fig. 11–5) was indeed an area of upward flow of warm moist air and that the cold dry air coming in from the west and southwest was actually air coming down toward the surface, subsiding and cutting into the cloudy region.

As is well known, fronts are enormously complicated. British meteorologists have found that in many fronts, in addition to the clouds which are not by any means uniform or standard from one front to another, there are dry areas. In addition, they find that in every front there are varying types of cloud systems. Thus, it could be assumed that in all major frontal systems, the air has had a history of upward motion coming from an area where the air was moist.

The difficulty in studying cloud pictures is that, although the cloud development is instantly recorded, the cloud has gone through some history during its development. It is possible that although the cloud was produced in the expected way, namely by upward motion of moist air, the cloud may, by the time it is observed, have been transported to a region where the motion is downward, or perhaps just horizontal, and might persist for some time. Thus, it cannot be certain that a cloud, observed at an instant in its development, represents upward motion.

An apparent finding made in one of the studies at the Meteorological Satellite Laboratory is that if there is a cyclonic system which is still growing, in other words, if, at the upper levels (500 millibars and above), a closed isobaric system or closed contour system has not formed, the cloud does represent very well the major regions of upward motion. In those cases it probably would be justifiable to assume that the cloud does represent a region of rising moist air.

Figure 11–8 shows a storm (studied in detail in ref. 2) which is a little further in development. In this case, also, although observational coverage is perhaps better than it is in some of the Southern Hemisphere oceans, details are found which are not usually obtained from conventional reports. This figure represents a composite of pictures taken in the region of the Gulf of Alaska. The cyclone is represented by an array of clouds surrounding a smaller cloudless area at *A*. It looks as though the cold air has come around all the way into the cloud area and the spiral is more pronounced than the one shown in figure 11–6, suggesting a still further state of occlusion process of an older storm. The surprising item is the presence of the small vortexlike cloud

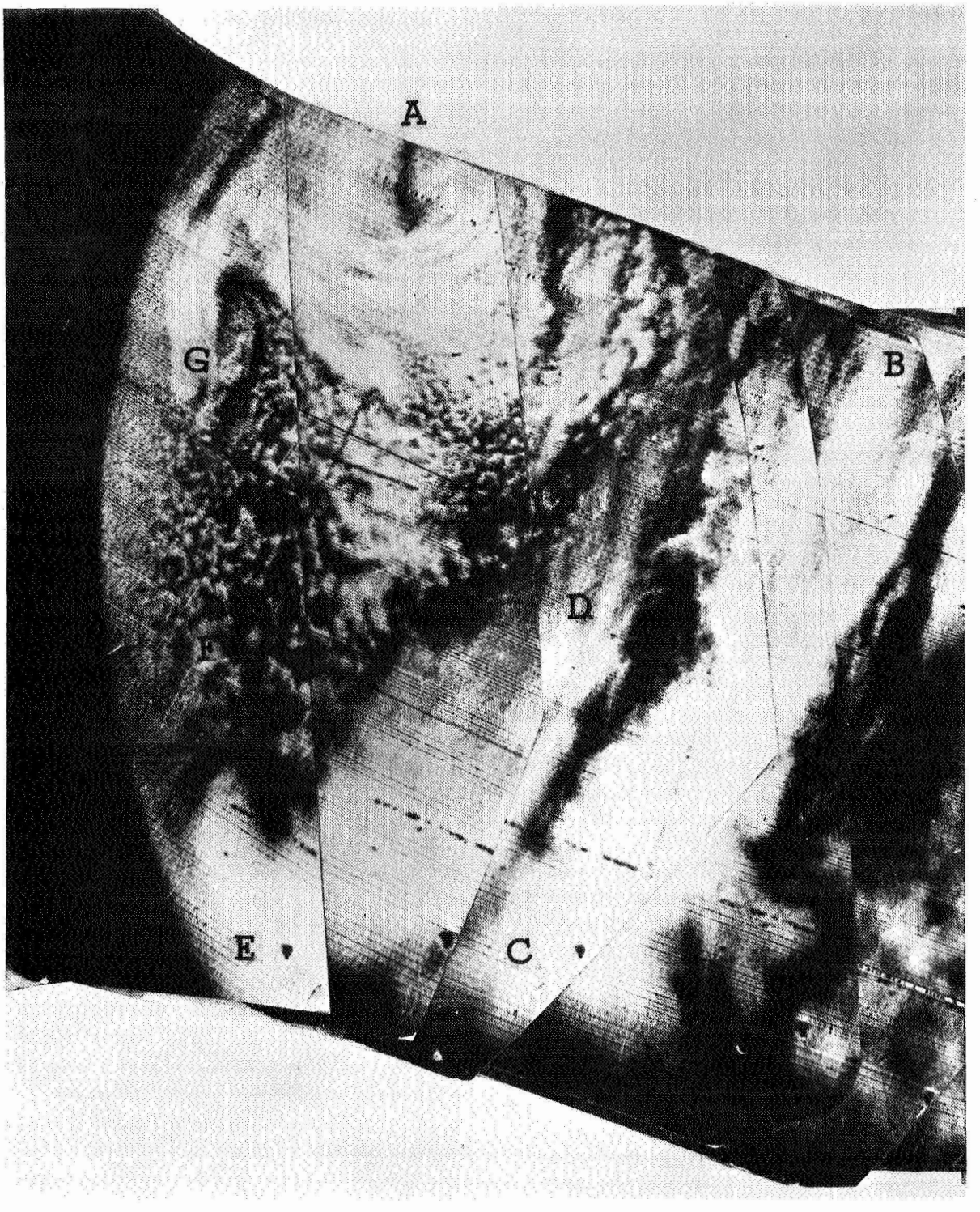

FIGURE 11–8. Composite picture of Gulf of Alaska storm and adjacent synoptic features. Pictures were taken at approximately 2200 GCT, April 1, 1960.

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system at G which is behind or to the west of the major cyclonic cloud system. There was no indication of this on any of the maps. The Gulf of Alaska area is by no means well reported. There is one radiosonde in an area about the size of the United States, so it is not too surprising that such a small-scale system in the circulation would be missed. It is presumed that the system at G is the remainder of an old occlusion, still part of an older frontal system, the exact history of which is not known.

Associated with the major cyclone is the main frontal system BC and the cloud DE which is separated from the main frontal system. Then, there are the more broken-up clouds at F, arrayed, in part, in sort of a circular pattern. If the main cloud surrounding A is closely examined, the streaks mentioned previously are seen. The impression is that this streaky cloud is lying above the broken-up clouds; in that case, the streaky cloud would represent the altostratus or cirrus overcast above the lower cloud deck. One opinion is that this pattern represents, in this case, the cloud system in the cold air which is capped by a rather low-level inversion, say, an inversion below the 700-millibar level. The cellular types of clouds at F will be discussed in subsequent papers.

What is interesting also in this picture is the cloud DE. The synoptic pattern that was associated with this cloud represented the cyclone and the cold front. On the cold front was a wave which was shown as very weak. Cloud DE was analyzed as being associated with a wave system that is rather faraway. Had this picture been studied at the time the analysis was made, perhaps that wave would have been given more emphasis; it turned out that in the next 24 hours the wave did develop and become a major cyclone.

Figure 11–9 (fig. 1 of ref. 2) is the synoptic pattern associated with the storm shown in figure 11–8. The heavy broken line is the orbital path of the satellite. The pictures were taken at the positions indicated by dots. The frontal system is seen in the foreground. The wave in the southwest is outside the region of the picture.

Figure 11–10 (fig. 5(b) of ref. 2) shows part of the cyclonic system in the Gulf of Alaska and the associated surface chart. Note the frontal system. This frontal system, lying

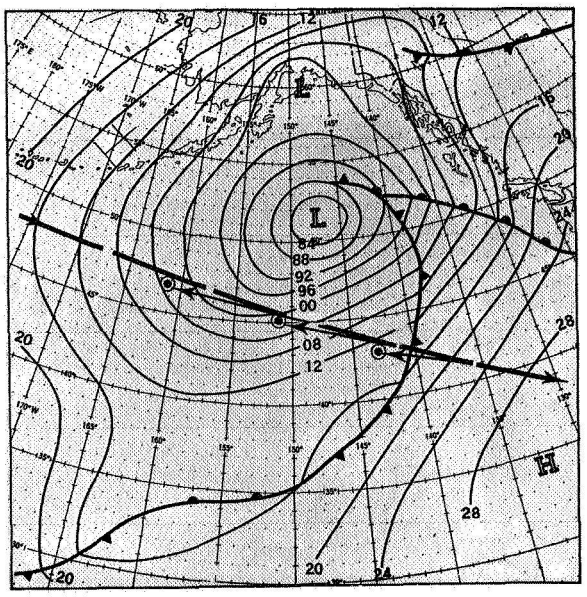

FIGURE 11–9. Sea-level analysis with track of satellite indicated by heavy line. Circled dots indicate principal points of pictures and arrows show orientation of camera for each picture. 0000 GCT, 2 April 1960.

more or less through the clouds, was substantiated by some surface reports. Therefore, the location of the frontal system was known. In the case of the Midwest storm shown in figure 11–5, the clouds were on the edge of the front; that is, the clouds were almost entirely to the east of the cold front, in warm air. In figure 11–10 the cloud system straddles the front and the cloud may actually be in cold air to a large extent. Apparently, this situation was found often by the British meteorological flight, namely, that the clouds could be in either place although, predominantly, they were in the warm air.

This, perhaps, is another fruitful field for study of the detailed dynamics and structure of frontal systems in relation to their cloud patterns. Why, for example, do these various systems exist and how can they be used to find the solutions needed to problems in forecasting and in basic understanding. From various studies it has been learned that these frontal systems usually represent regions of rather sharp temperature gradients and it appears that this is true also in these cases (figs. 11–5 and 11–10). When the system gets very old, the temperature contrast is by no means as great as it is in a younger system.

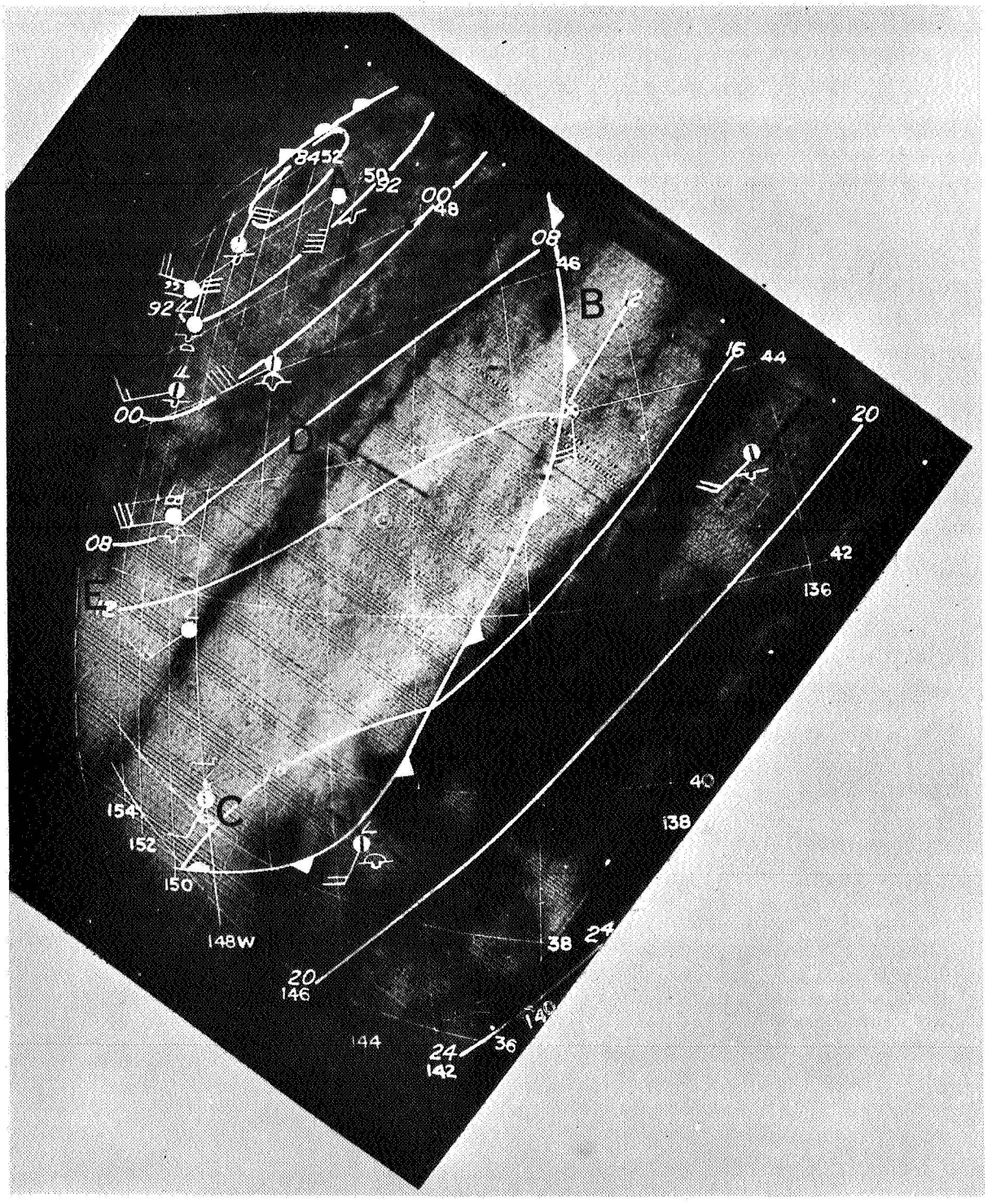

FIGURE 11–10. Picture of cloudiness south and southeast of the Gulf of Alaska cyclone. 2° latitude-longitude grid; principal point indicated by circled dot; surface analysis and data for 0000 GCT, April 2, 1960 superimposed.

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Figure 11–11 shows the upper air information and also dashed lines which represent the regions of vertical motion. In this case the vertical motion was computed to be upward, which would be in agreement with the cloud system. But, because of the break in the cloud,

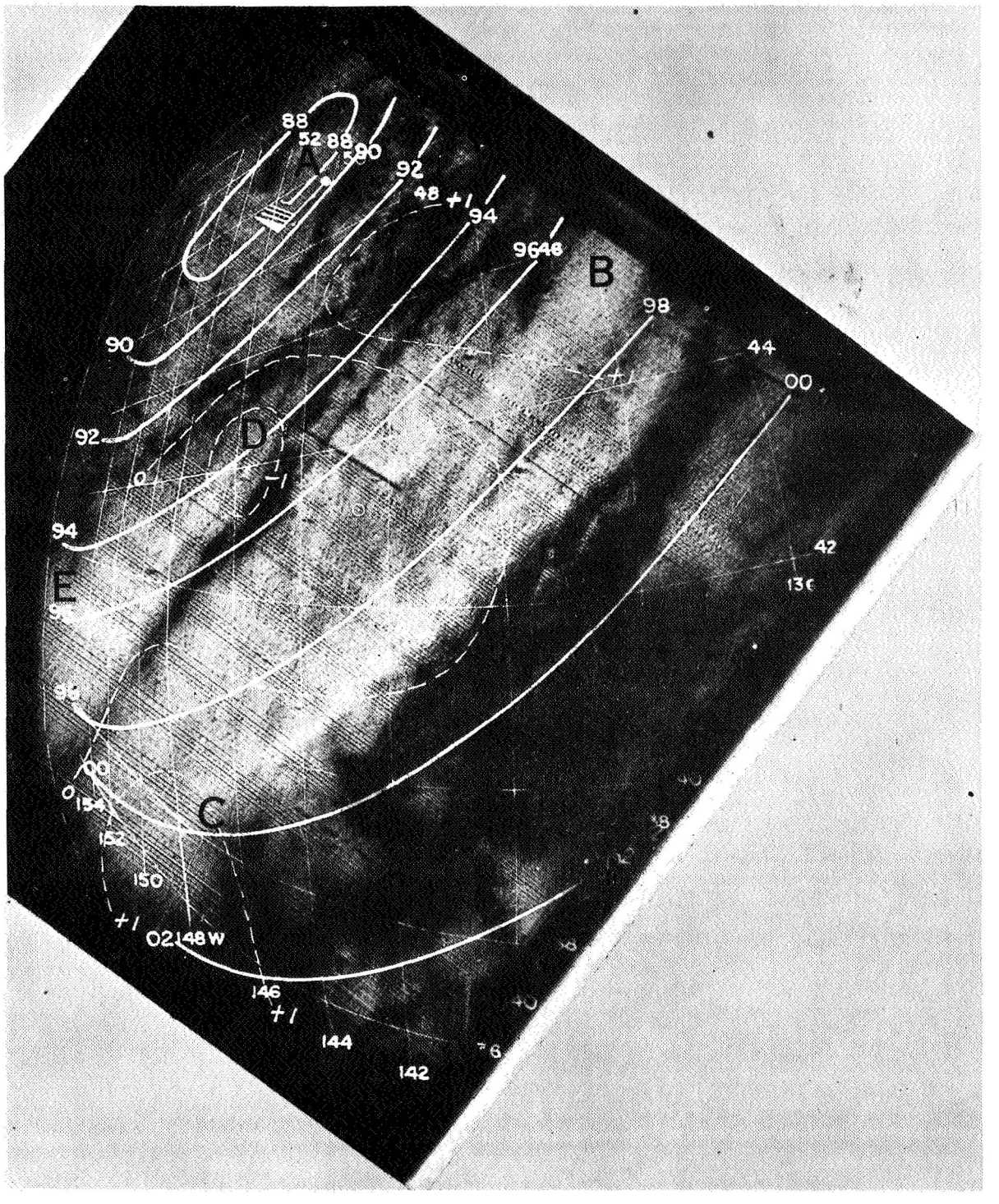

FIGURE 11–11. Same cloud area as in figure 11–10. 2° latitude-longitude grid; principal point indicated by circled dot; 700-millibar contours and 600-millibar vertical motion (dashed) in cm./sec.; data for 0000 GCT, April 2, 1960.

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it was suspected that perhaps the vertical motion actually had two centers rather than just one. This break in the clouds would be in the region where the upward motion was absent or even downward. Thus, again, some detail in the estimate of the initial conditions might be obtained.

Figure 11–12 shows another storm (discussed more fully in ref. 3) in the Atlantic Ocean which was a rather mature storm. This system is to the west of England. It so happened that this storm system was photographed on two separate orbits, 100 minutes apart. As the satellite goes around the earth, if it passes an area near the northern part of one orbit, on the next orbit it may cross the area again. Note the persistence over a 100-minute interval of some rather small-scale features. Part (*a*) is the northern part of the storm; part (*b*) is the southern part. Part (*a*) was taken early on April 2, 1960, and part (*b*) was taken 100 minutes later on the same day. Land features are labeled to help with the orientation. The Mediterranean part of Spain is mainly cloudless. The lower right of part (*a*) shows snow in the Alps. There were very few clouds in the Alps region at this time, as verified by surface reports. Italy is to the south as marked in the figure. Part (*a*) shows holes in the clouds over the Bay of Biscay, near France and Spain; the clouds in the Atlantic storm extend across Spain.

It was noticed that the cloud system surrounding the storm with the holes over the Bay

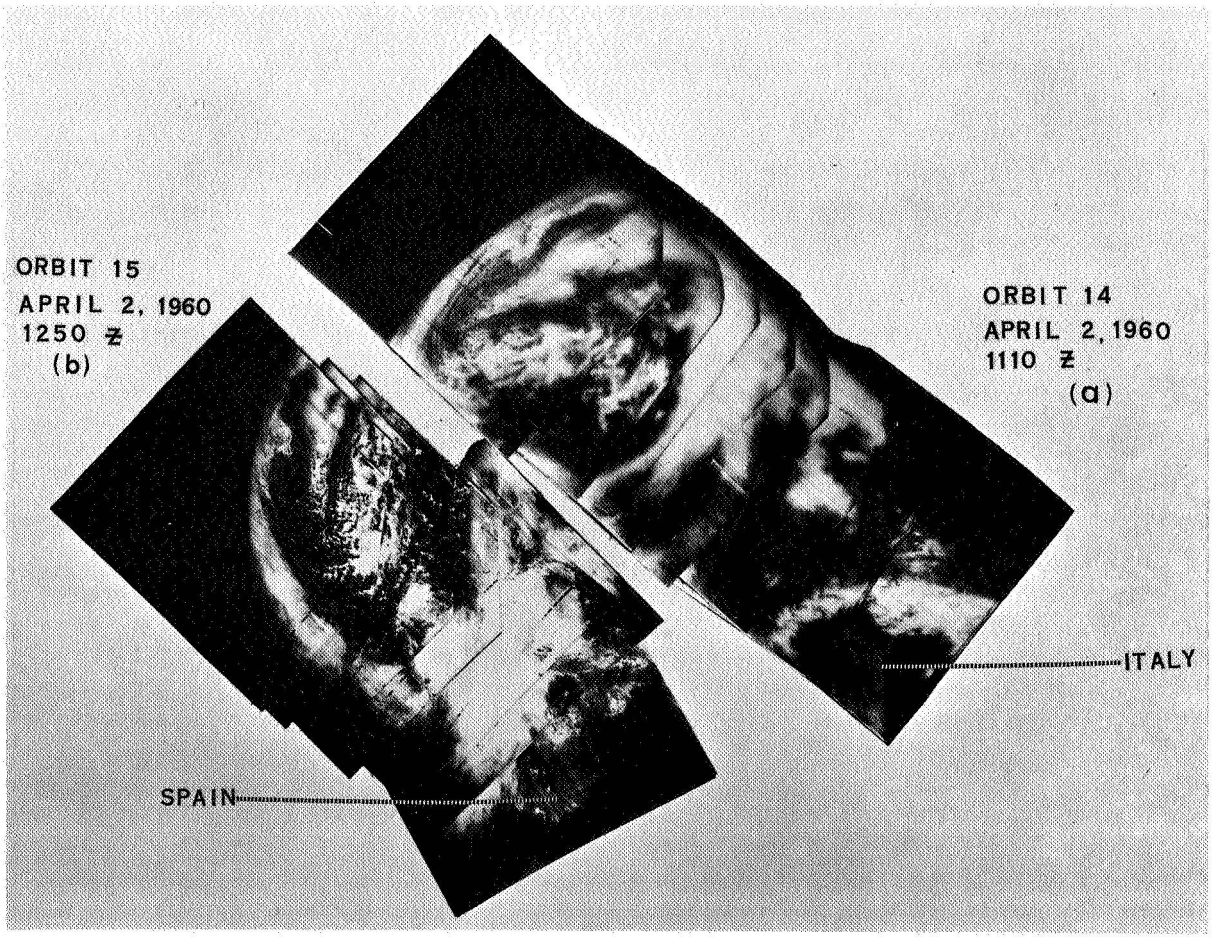

FIGURE 11–12(a). Composite of frames photographed at about 1110 GMT, April 2, 1960, showing stratiform cloud surrounding cumuliform cloud in an Atlantic Ocean vortex.

FIGURE 11–12(b). Composite of frames photographed at about 1250 GMT, April 2, 1960, showing the same Atlantic Ocean storm 100 minutes later.

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of Biscay (pt. (*a*)) came into an arrowlike projection. The same formation appeared 100 minutes later. This cloud arrow protrudes from what might be called the wall of the cyclonic cloud. From this region some cloud streaks, rather thin lines, are spreading outward. They are also present 100 minutes later and they seem to be going into the main body of the center of the storm.

The broken-up cumuliform clouds get brighter as they go from the region of northerly flow, where the clouds seem to be much more suppressed in vertical extent, to the region of southerly flow, where they get brighter. It is assumed that they are of higher vertical extent in the region of southerly flow, although the height of the clouds cannot be determined directly from the picture. There is an interesting swirl of clouds north of the Alps on the northeast side of the main cloud formation. The air was actually flowing around cyclonically and then branching off to the east. It may be wondered whether this cloud, which existed over Germany, might not be a representation of a small anticyclonic swirl branching off the main flow.

By various techniques something may be ascertained about the geographical location of the individual cloud elements. Figure 11–13 is a map which shows the storm cloud formation, pictured in figure 11–12, over the British Isles, Ireland, the French coast, and Spain. The cloudless region on the right is over Italy. The satellite traveled along orbit 14, coming across the Alps and Italy, and 100 minutes later it traveled along the orbit 15 track across Spain and North Africa. This map represents the composite information about the storm. Shown

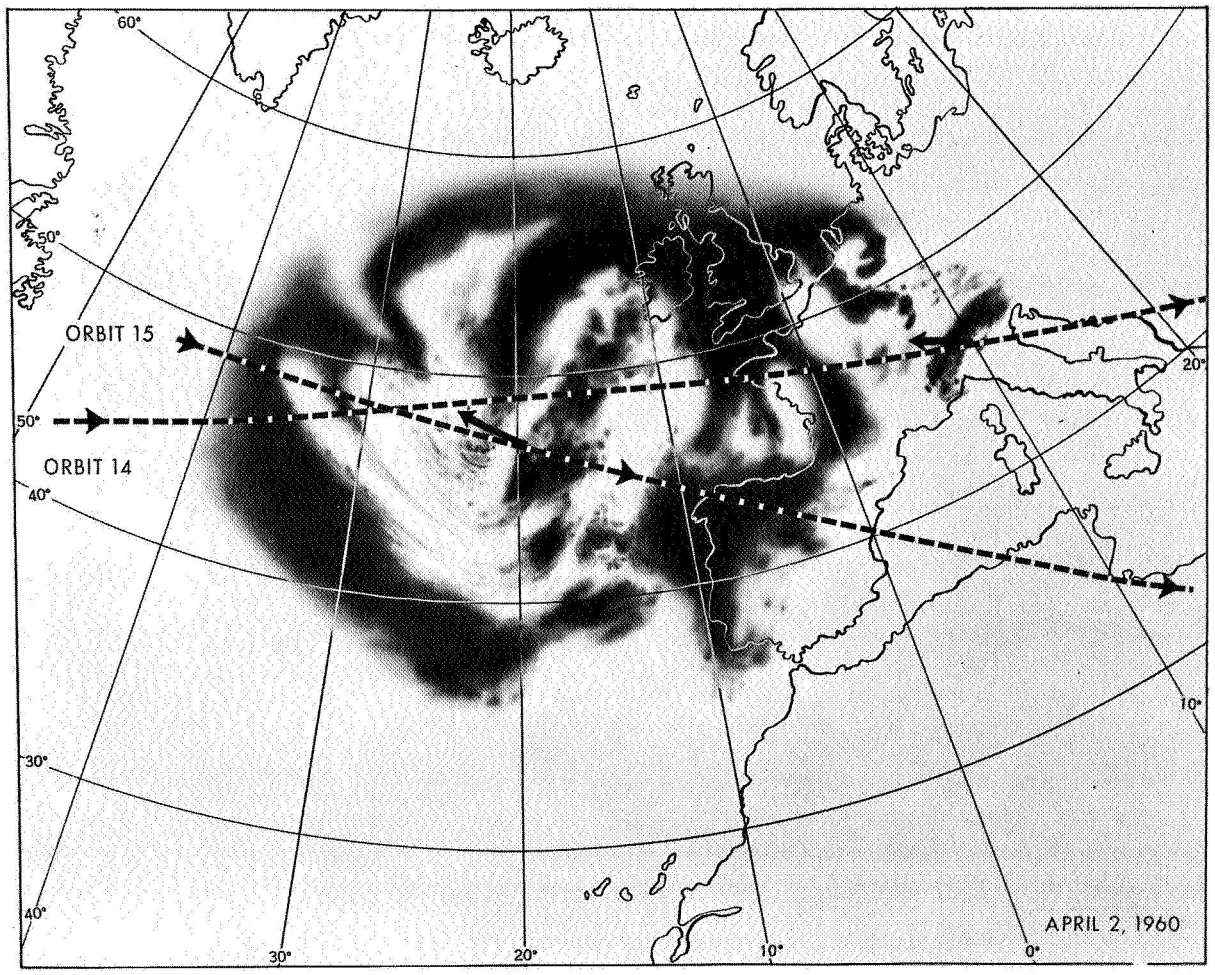

FIGURE 11–13. A sketch of the pictures in figure 11–12 arranged in proper geographic location.

again are the two holes over the Bay of Biscay and the broken cloud pattern. The arrow is mapped at about 50° north and 20° west. It seemed reasonable to suspect that the cold source which was feeding this storm had been cut off because cloud now surrounded the storm completely. It turned out that this region was associated with a very deep cold airmass which extended to the tropopause. In the region to the east and northeast, warm moist air was flowing.

Figure 11–14 is the sea-level chart associated with figure 11–12. The hatched area is the stratiform cloud that surrounded the storm in the pictures. It has been included for purposes of orientation with regard to the synoptic features. The low center is very near the arrow; in the central region all reports showed clouds with vertical development, cumulonimbus, and cumulus congestus, but no overcast conditions. In the region where the frontal system is located, all reports indicated practically overcast conditions, or at least nine-tenths coverage, with various stratiform clouds; these reports merely show that the satellite pictures agree with the surface observer. The details of the pattern could not be obtained in any way other than from the satellite. The major cloud system was known, of course, from conventional observation. The frontal system was very difficult to locate accurately because of the fact that it was a rather old system and the contrast between airmasses was very weak. However, the analysts placed the front more or less in the middle of the cloud system, using the theory that in the older systems the clouds do not fall right on the edge of the front as they do in growing vigorous cold fronts.

Figure 11–15 shows the 500-millibar chart. It shows, as expected, that there was warm moist air flowing around the cyclone. Figure 11–16, which is the isentropic chart, shows the

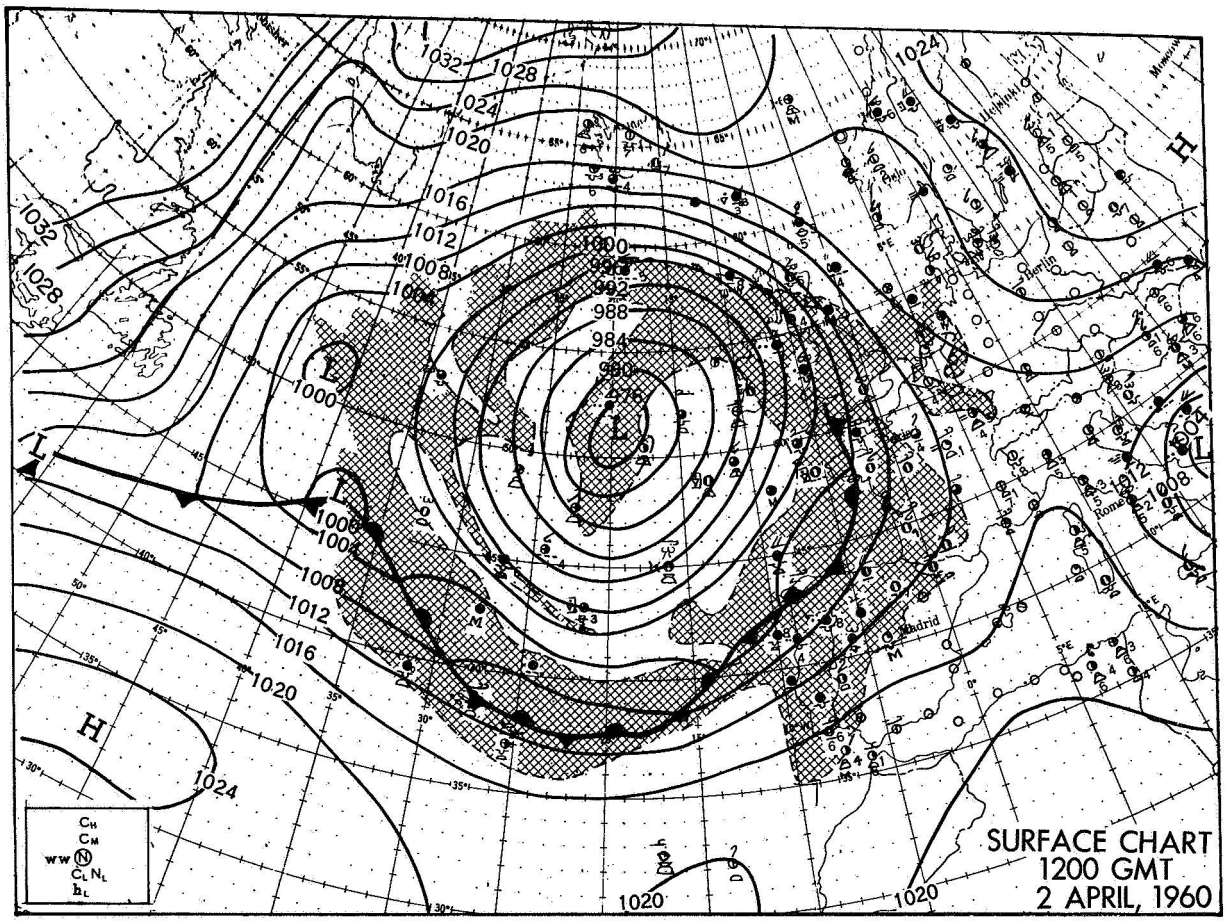

FIGURE 11–14. Sea-level chart for 1200 GMT, April 2, 1960, showing mature cyclone with outline of stratiform cloud area from figure 11–13 superimposed. Surface cloud observations are also shown.

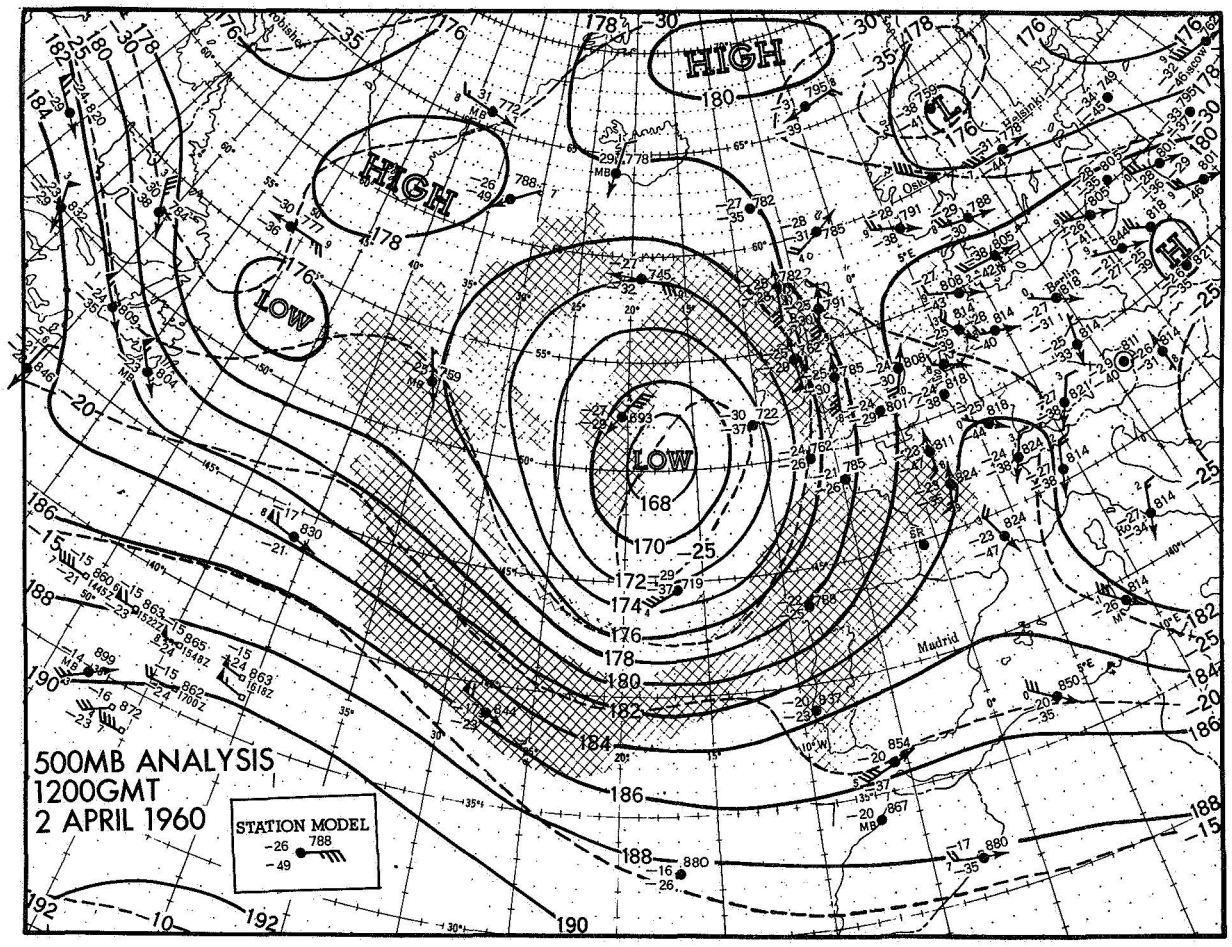

FIGURE 11–15. 500-millibar chart for 1200 GMT, April 2, 1960. Solid lines are 200-foot contours; dashed lines are isotherms; dewpoint temperatures are shown at lower left of each station circle.

airflow more clearly. The warm moist air was flowing up the isentropic surface from the southeast sector of the storm and cyclonically around. To the north reports were received from two ships (ships I and J). The variation of wind with height at these ship locations shows that this warm moist "tongue" flows between the stations. This agrees very well with the pictures of the clouds forming the arrow-shaped projection, with the moist warm air flowing around the cyclone.

In the center of the mass is a very high and cold dome of air, corresponding to the broken region shown in figure 11–12. In the region to the northwest conditions are somewhat more ambiguous and it is uncertain, on the basis of these data at least, that there is a flow of warm moist air. However, the presence of the cloud, unless it is one of those cases where the cloud was formed under one regime and now is gradually moving out into another (which does not seem likely in such an extended frontal system), would indicate a region where the motion is upward but perhaps not so strongly upward as in some of the other regions where it is very clearly indicated.

One other point is worth mentioning. In the region of the cold front, there is a deep cold mass of air which is shown in figure 11–16 and also warm air ahead of the mass. It is known that if air is flowing around the cyclone, and in such a manner that it is flowing around the cold air also, then the thermal wind equation requires that the wind should increase in magnitude with height; that is, the speed of the wind should increase with height.

This would mean that, if the regions where cold air lies next to warm air could be found in cloud pictures, as indeed they can in this case, it would be known that somewhere in the

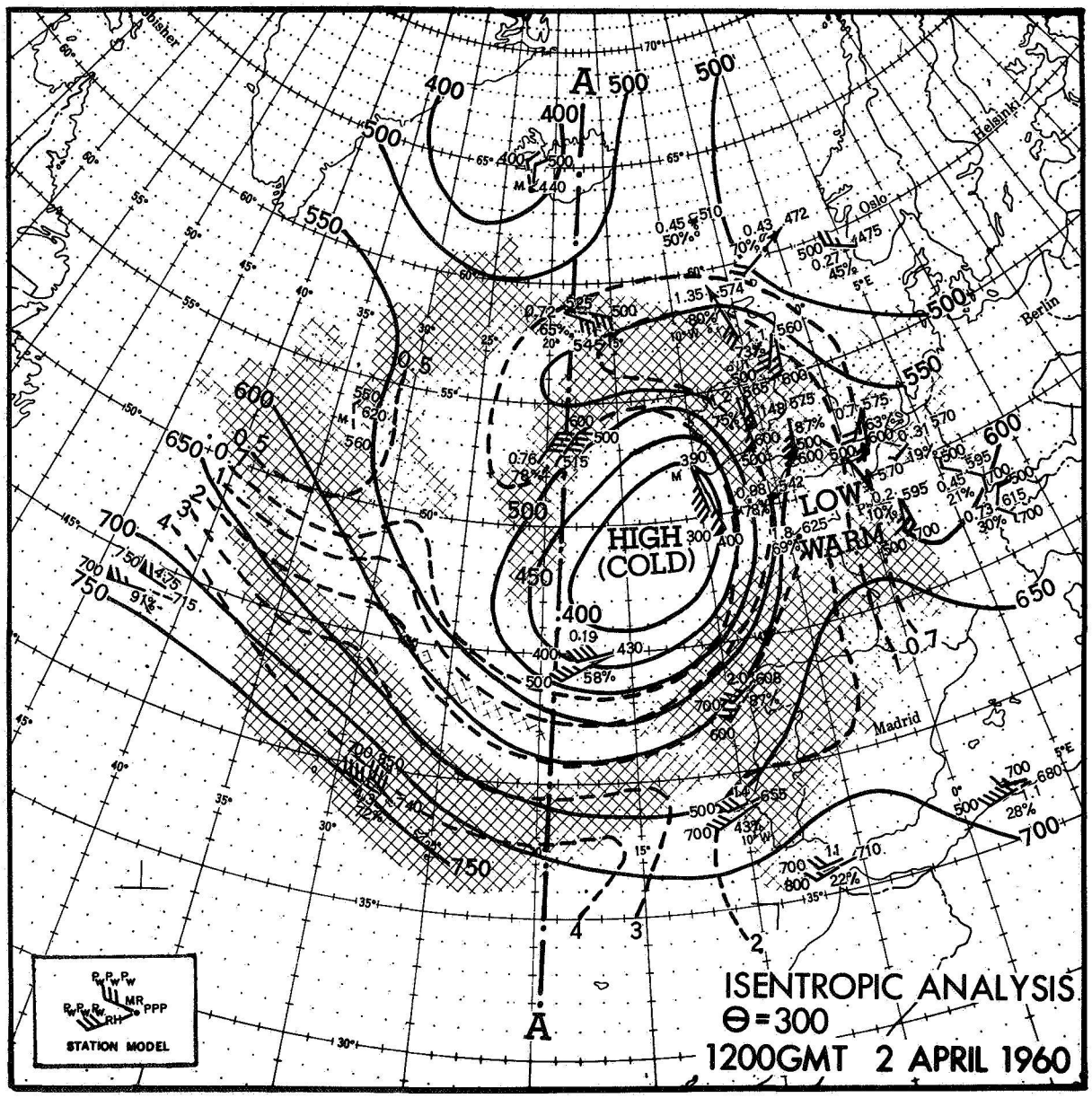

FIGURE 11–16. Isentropic chart (θ=300° K), 1200 GMT, April 2, 1960. Solid lines are isobars on the isentropic surface; dashed lines are lines of constant mixing ratio. Line AA shows the region of the cross section in figure 7 in reference 3. The winds are shown at two pressure levels near the level of the isentropic chart. High and low refer to the elevation of the isentropic surface.

vicinity of the boundary between the cold and the warm air there is a region of strong winds. It may be characterized as the jetstream if the winds become strong enough. Whether the winds were precisely at the boundary would depend on the relative slope of the adjacent airmasses and other factors. However, in the general vicinity of the boundary there is a region of strong winds. This region can be seen in figure 11–16. As would be expected in the case of a cyclone, the winds in the center are rather light. As the boundary between the stratiform cloud and the region where there is very little stratiform cloud and no cumuliform cloud is crossed, a region of high winds would be expected. Actually, there are winds approaching 60 knots across this region; then, the winds decrease in the general anticyclonic region. Several cases such as this have been examined. As might be expected, in a very

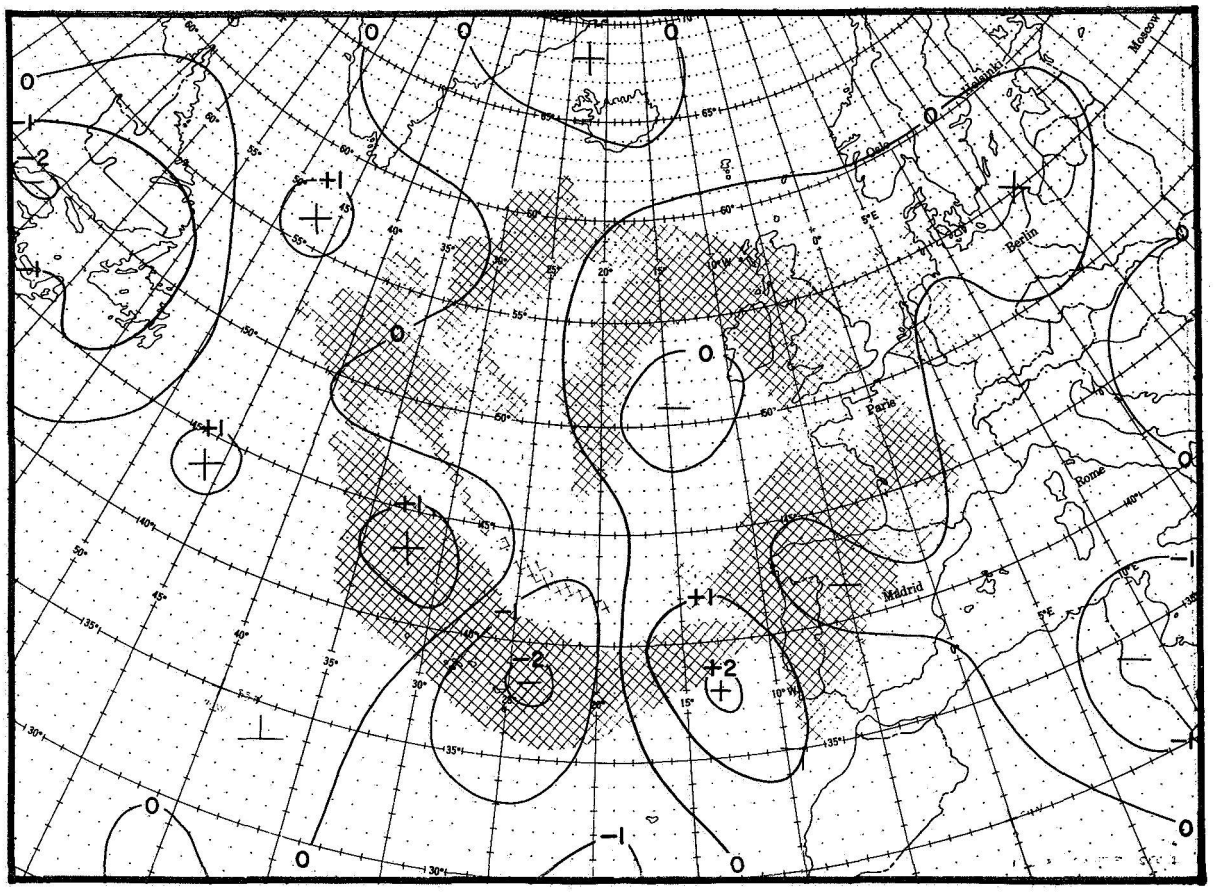

FIGURE 11–17. Vertical motion chart for 600 millibars at 1200 GMT, April 2, 1960, computed by JNWP unit. Units are cm/sec; a plus denotes upward motion; a minus denotes downward motion.

general sense, the region of strong winds aloft can be located.

Figure 11–17 shows the vertical motion field as it was computed by the U.S. Weather Bureau numerical prediction unit on the basis of what was believed to be the horizontal wind field at the beginning of a particular forecast period. In the middle of the region surrounded by stratiform cloud there is a region of downward motion which agrees with the belief that this is not a region of little motion on the isentropic surface. On the other hand, to the right, or west, of the arrow there is still a very weak upward motion. By contrast, there is strong upward motion near 37° north and 13° west. This region, according to the flow in the cloud, would probably represent a larger upward motion than shown. Perhaps more important is that the region centered near 37° north, 25° west, which lies adjacent to the one just mentioned, shows a strong downward motion and is a region where substantial cloudiness still exists. In the absence of any other information this region would probably be considered one of upward motion, not downward motion. Thus, this might be a case which, because of the lack of upper air data, does not permit a good estimate of vertical motion. In this area some improvement could be made in the tools which are available to the forecaster.

Figure 11–18 is a cloud mosaic of TIROS I pictures across the northern Pacific. The frontal systems are plain. The cloud is branching off in an anticyclonic manner to the west of the central occlusion. Also shown is the broken-up cloud field which is associated with the air in the anticyclonic colder air. Where the cloud edge is sharply defined, strong winds would be expected at an upper level, as previously mentioned. There is cold air coming into a region with a strong frontal system. Thus, it would be expected that warm moist air is flowing side by side with colder air, so aloft there should be a region of stronger winds.

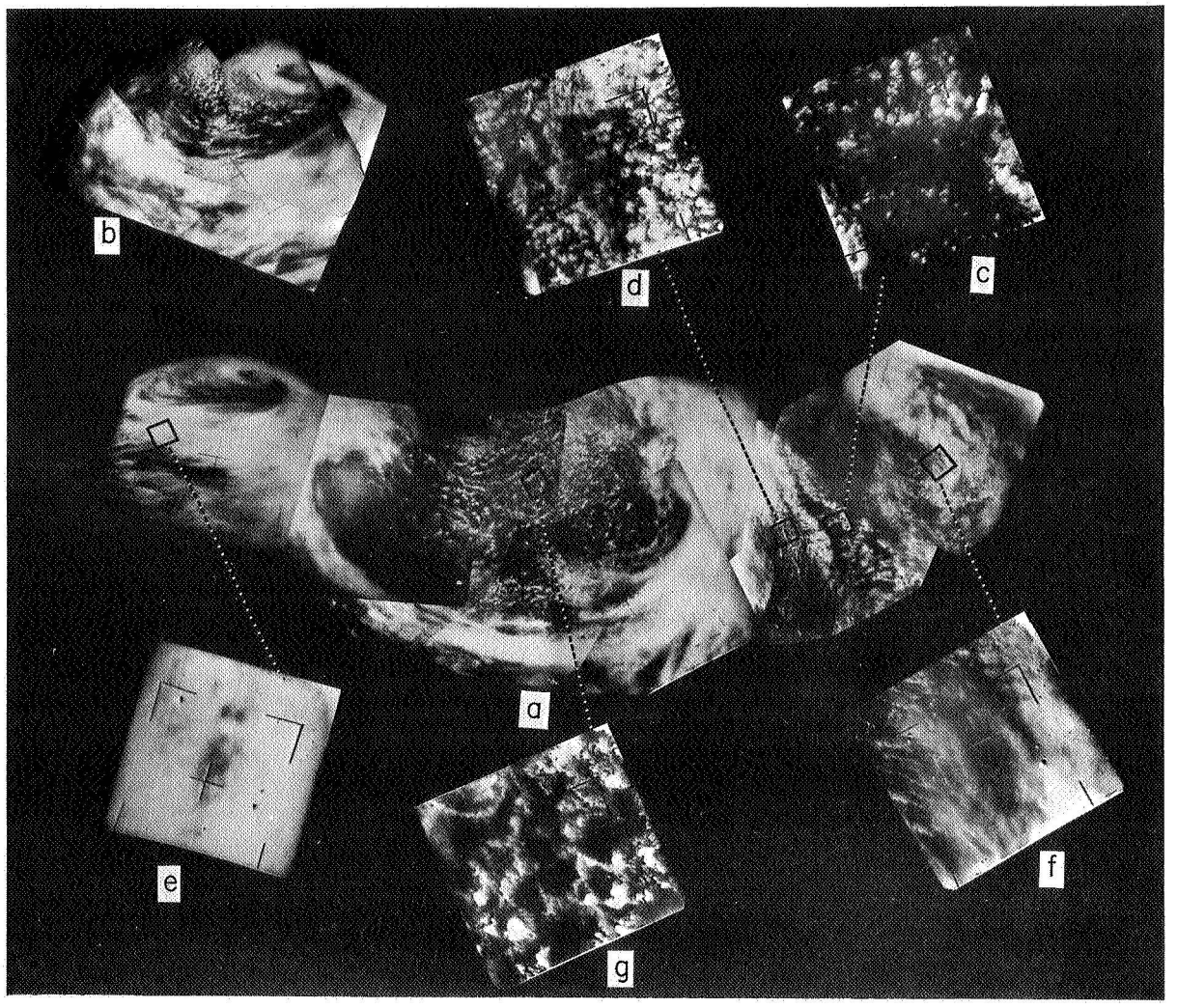

FIGURE 11–18. (a) Cloud mosaic of TIROS I pictures across northern Pacific, May 20, 1960. (b) Cyclone detail (mosaic of wide-angle pictures). (c), (d), (e), (f), and (g) are narrow-angle pictures of mosaic.

Some details of narrow-angle pictures in this region may be of interest. For example, picture (*g*), taken in the region shown by the connecting square, shows some of the detail of the individual cumulus clouds, which are partially arrayed in circular patterns. There is, especially in this region, lack of agreement regarding the extent to which these clouds are built up. Some meteorologists believe that these clouds are built up to large heights. Others are rather skeptical; but it is a region for which there is very poor upper air data so that the results cannot be verified.

Figure 11–19 gives a better illustration of the region where strong winds might be expected, with contrasting flows of cold and warm air. Although the location of the "jet" cannot be known, it is believed that it could be placed along a line paralleling the sharp edges of the clouds near the cold fronts of the two main systems. Other information may have to be used to decide how to connect portions of the jet. Parts of the jet could probably be identified on the basis of the pictures alone.

Figure 11–20 shows a system of cyclones in the Southern Hemisphere. Picture 3 shows a stratiform cloud completely surrounding more broken-up cloud; between the two is a cloudless area. This looks very much like the storm in the Atlantic which has just been described (fig. 11–12); it could, therefore, be speculated that this pattern represents a cyclone in a rather mature state of development in the Southern Hemisphere. Picture 6 shows a storm which

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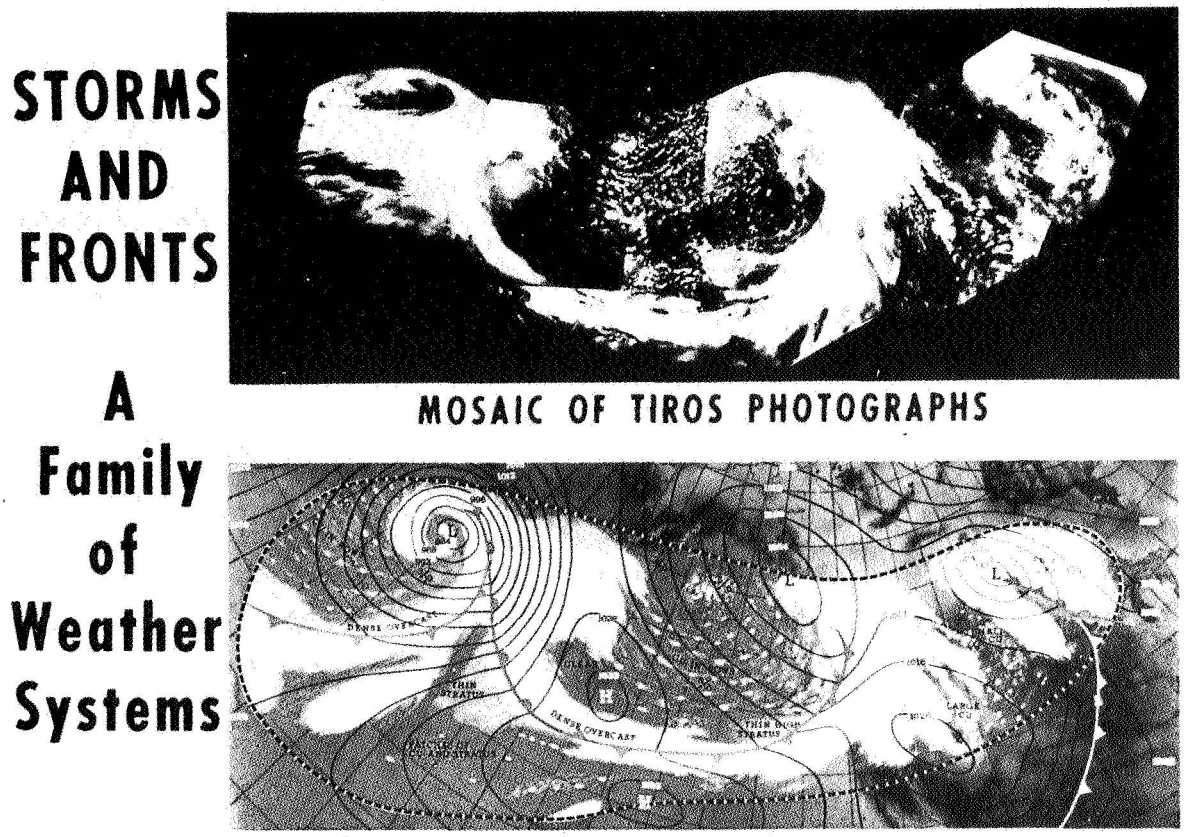

FIGURE 11–19. Cloud mosaic and matching weather map, May 20, 1960.

was discussed in reference 4. The cyclone is defined, to a certain extent at least, by the cold air which has penetrated the mass of the cloud. Actually, the cold air is coming far around the cyclonic pattern. Thus, this is a fairly advanced state of cyclonic development. It was known that this storm was located between South America and Africa. There was one ship report available to the South American analysts; however, the picture was not available when the analysis was made. The ship reported a very low pressure. A storm was therefore placed on the weather map near the ship location. However, the cloud pictures of the storm show that it was far to the east of the ship and that no large cyclonic system was present near the ship position. An examination of the situation revealed that the report and picture could be made consistent by merely changing the first digit of the coded transmission of the barometric pressure from a nine to a zero. Everything falls in place with the storm faraway from the ship and with reports from the ship fitting in rather well with the remainder of the cloud pictures. This is an excellent example of how cloud pictures in a region with practically no conventional information can be of great value in analyzing the synoptic situation.

The ability to derive all the information from cloud pictures is largely undeveloped. What is needed is for the whole meteorological community to accept these cloud pictures as one of the best observations obtainable, especially in areas where there are few conventional observations, to use them to attempt to understand what the cloud patterns mean, and to improve forecasts in the operational service in those areas.

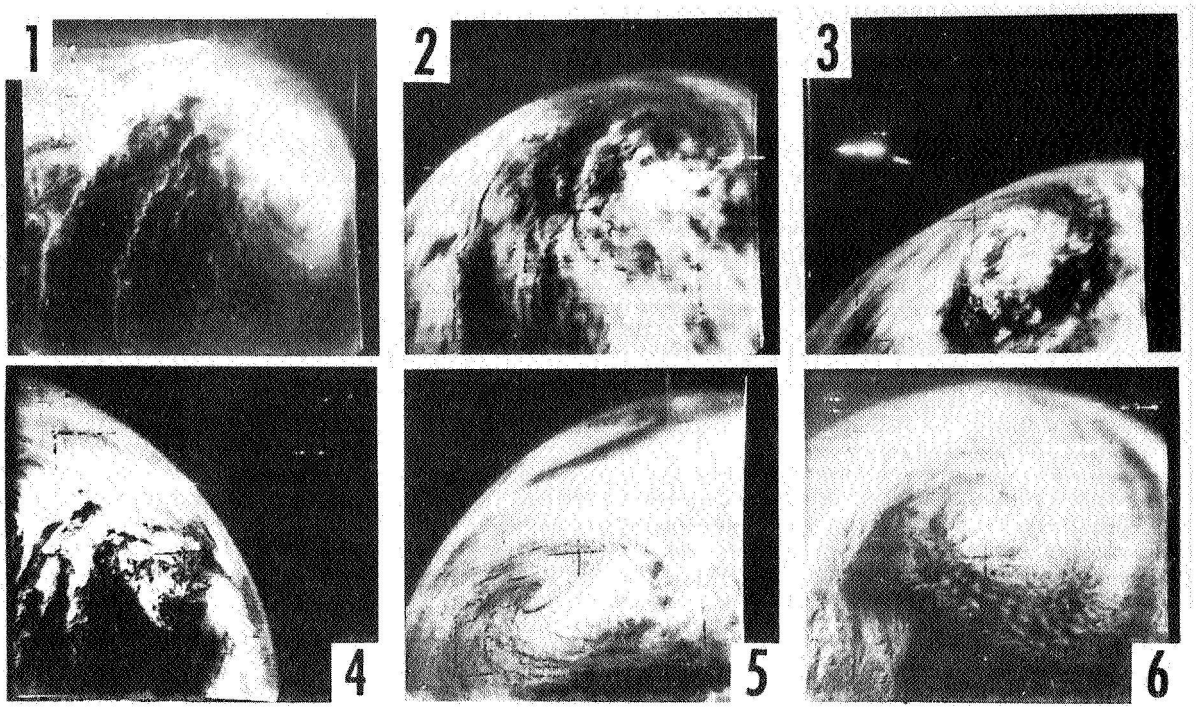

FIGURE 11–20. Southern Hemisphere cyclones as seen from TIROS I.

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Question Period

MCCULLOCH, Canada: I was wondering if some of the pictures, especially figures 11–5 to 11–7, the Midwest storm, might not lend a little support to the Canadian multifront model—to the idea that there may be more than one major frontal system.

FRITZ: It might well be. Certainly, I would investigate that. My recollection is that in the analysis of that storm, we did not detect in the radiosonde data available any distinct airmass difference. Perhaps, we were not looking at it in terms of the particular model that you have in mind. It would be a very good point to study.

PATRICK, Nigeria: Correlation is rather lacking between the field of vertical motion, as computed by the Numerical Weather Prediction Unit (JNWPU) here, and the cloudiness. Do you feel that the field of vertical motion is not giving a correct idea because of a fault in the model approximation or because the correlation of cloudiness with vertical motion, in general, might not be very helpful to practicing meteorologists in supplementing their forecasts?

FRITZ: I think that in areas like the United States, for example, in the central United States where there are ample radiosonde data, that the vertical motion fields, as computed by the JNWPU groups, are in the main adequate. But in an area like the Atlantic, where even though there is probably a greater density of radiosonde information than in any other ocean except the southern Pacific where there are many islands, I think the data are inadequate to compute the vertical motion field well. Over the ocean, especially if there is a cyclone which is still in the state of development, the clouds represent the vertical motion field better than the JNWPU computations. Since that is true, we have a possibility of improving the JNWPU product in those areas. This would not mean that we could do it everywhere, and it would not mean that we could do it with any cloud system. But with a great many cyclonic systems, and in ocean areas, we definitely have a prospect of improving the vertical motion field estimate.

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LEVI, Israel: In the same context, with respect to correction of the vertical motion fields from clouds, I feel that it would be rather difficult to get the correct picture knowing that extensive stratocumulus decks, for instance, often cannot be differentiated from extensive altocumulus decks. The considerable difference in height might mislead us quite a lot in that case.

FRITZ: Yes, that is a very important point. I think if we had only the cloud pictures, that would be a rather serious handicap, although perhaps not hopeless. However, we have now another tool which may help: the satellite radiation measurements, which will be discussed in subsequent papers. With the aid of these radiation measurements, we have a possibility of estimating whether the cloud is very high or very low, at least to differentiate between extensive stratus decks, say with a top of 5,000 feet, and extensive altostratus, with a top of 15,000 or 20,000 feet. We have a very good prospect of being able to detect large differences with radiation measurements. When we get to the point where that becomes operational, the objection which you mentioned, which is a very serious one, may, in part at least, be overcome.

PATRICK: Are the bright spots which are shown in the observations due to short waves reflected to the satellite? In certain areas there are desert regions, for example, the Sahara in Africa. Some of the meteorologists in countries toward the south of Africa will be interested in focusing on things like dust haze. In that case will it be possible to distinguish in the pictures between the type of radiation reflected from the dust haze and that from thin clouds, and will dust haze be distinguishable from the ordinary sand in the desert?

FRITZ: Actually, I do not know the answer to your question. Perhaps it would be a very good thing for someone from that area to investigate the TIROS pictures to see what can be done. I have studied a few pictures along the Mediterranean, African coasts in the area of Libya and Tunisia, and I have examined the ground features. In those cases there were no clouds, and one could see very clearly the sand dunes in the land features. The sand dunes themselves have enough contrast with the surrounding terrain so that one can detect them. On the other hand, along the Mediterranean coast, there were small white spots, which looked like small cumulus clouds. It is doubtful that the clouds could be checked from surface data, but there probably were small cumulus cloud streets. Several meteorologists who have looked at those white spots have thought that they were cumulus clouds which you could see against the very bright ground which lies not far from the Mediterranean coast. But what an extensive cloud deck would look like, I am not at all sure.

RASOOL, Institute for Space Studies: I want to ask about the polarization measurements from the top of the clouds. Dust would not make any difference to the albedo, would it?

FRITZ: It might. We do not have any polarization measurements. However, I would suppose, from suggestions that have been put forth about the estimate of cloud tops by measuring polarization, that if the degree of polarization were measured, looking down, an estimate of cloud heights could be obtained. The idea is that the air lying between the satellite and the cloud would polarize the light and that the amount of polarization would depend on the amount of air which lies between the satellite and the cloud. If this would work, then one could distinguish, for example, between a cloud which was high and dust which, I presume, would not be so high. But we do not have any information about that.

RASOOL: Could the droplet size be obtained by polarization?

FRITZ: I do not know.

LANGLO, WMO: Have you thought of any program to compare the cloud observations obtained by conventional means, a network of the densest type as in Europe, with cloud observations from satellites? Have you thought of any program like that of Professor Bergeron who has for many years proposed that the whole method of cloud observations by normal meteorological stations be revised, in the sense that they are not really giving what they ought to give?

FRITZ: We have not considered the European network. I am hoping that the meteorologists in Europe will give the problem serious thought. But we have looked rather closely at the networks in the United States and Mr. Erickson, in paper 12, is going to discuss topics related to your question, namely, what is the relation between what is seen in the satellite picture and what is seen from the surface and, also, what is seen from airplanes. Sometimes, fields of small cumulus clouds as seen by the satellite may appear as haze or a thin cirrus from the ground. This relationship is being studied. Also under consideration are codes for defining the cloud systems pictured by satellites. There definitely is a need for classifying cloud patterns as seen from satellites in terms of the physical processes producing the patterns.

TEPPER: If I may add a few remarks relative to the question: We have in the United States a severe-storm research program which combines a very dense network of surface observations, special upper air observations, and an intensive aircraft and radar program. In conjunction with this research program, the satellite data will be used to define cloud systems.